APPENDIX 2C

A COMPARATIVE STUDY
OF FLORIDA'S MOST SEVERE TORNADOES
WITH THOSE
IN OTHER PARTS OF THE CONTINENTAL U. S.

Dr. Edward M. Brooks, Professor,
Department of Geology and Geophysics
Boston College, Chestnut Hill, Massachusetts

Harold P. Gerrish, Assistant Professor,

Homer W. Hiser, Professor, and

Harry V. Senn, Associate Professor,

Institute of Marine and Atmospheric Sciences,
University of Miami, Coral Gables, Florida

DOCKET NO. 50-335

FLORIDA POWER & LIGHT COMPANY
MIAMI, FLORIDA

TABLE OF CONTENTS

A COMPARATIVE STUDY OF FLORIDA'S MOST SEVERE TORNADOES WITH THOSE IN OTHER PARTS OF THE CONTINENTAL U.S.

1.0 INTRODUCTION

It has been evident for some time that Florida tornadoes are considerably less intense than the AEC model which was obviously derived from those which have occurred in other parts of the continental U.S. The purpose of this report is to document Florida's most severe tornadoes and to compare these as quantitatively as possible with major tornadoes in other parts of the continental U.S. in order to show that the current AEC model is excessive for Florida.

While thousands of continental tornadoes have been observed in the past, quantitative data on maximum wind speeds and central pressures within the central vortex are practically non-existant. Doppler radar can provide direct measurements of wind speeds along a radial from the radar location; but only a few measurements have been made during the past 10 years due to the lack of an organized doppler network in the tornado areas.

For a few of the intense continental tornadoes, it is possible to derive windspeeds indirectly from their dynamic pressures on structures that failed and/or from static barometric pressure observations inside or near the funnel, as has been suggested by Brooks(1) in a comprehensive survey article. Because of the uncertainties involved in these derivations, the numerical results cannot be taken too literally. Unfortunately, static pressure data do not exist for Florida tornadoes and limited data are available for wind computations based upon dynamic pressure.

The relative severity of tornadoes may also be determined by use of other methods. One such method is the analysis of the micro-and mesoscale synoptic conditions known to be necessary for severe tornadoes. Another is the use of statistics on deaths, damage produced, etc.

The procedure will be to develop the severity of continental U.S. and Florida storms and to compare the maximum wind speeds which might be expected in them.

2.0 DETERMINATION OF TORNADO WINDSPEEDS

2.1 Direct Measurements of Wind Speeds

Observations by wind instruments furnish the most accurate measurements; but unfortunately are limited to minor tornadoes or to the outer portions of major tornadoes. Inside severe tornadoes, the equipment is destroyed before the maximum wind at that point is reached. Remote sensing by the use of Doppler radar has probably provided the only reliable measurements to date of the particle speeds in the core boundary regions.(2)

2.2 Indirect Measurements of Wind Speeds

2.2.1 Determining the speed of the wind from its dynamic pressure

For winds strong enough to produce damage, a minimum dynamic pressure of the wind can be found. It is equal to the computed pressure necessary to produce some particular damage. Engineering estimates can be made of the force required to produce the observed displacement or deformation of selected objects of known mass or internal strength.

Let the kinetic energy of the wind ($1/2\ mv^2$) be used to do the work (Fd) of moving an object a distance of d:

$$1/2\ mv^2 = Fd \qquad (1)$$

m = mass of air
v = speed of wind

Let the object of cross sectional area A sweep out a volume V (equal to Ad) as it is replaced by the same air volume V (equal to $\frac{m}{\rho}$) (where ρ = air density): Divide (1) by the equivalents of V:

$$1/2\ \rho v^2 = \frac{F}{A} \qquad (2)$$

and

$$v = \left(\frac{2F}{\rho A}\right)^{1/2} \qquad (3)$$

This windspeed value applies only to the place and time of the damage and may fall short of the maximum windspeed of the tornado.

2.2.2 Determining the windspeed from its static pressure

From the lowest reading of a barometer, the pressure drop below the ambient pressure outside the tornado is computed. It is assumed that the kinetic energy of the wind is derived from the work done on the air as it moves from the ambient pressure to the minimum pressure in accordance with a simplified Bernoulli equation. However, it is assumed that half of this energy will be lost due to the friction between the accelerating air and its more stagnant environment.

The work of the pressure gradient force (F) is:

$$Fd = (A\,\Delta p)d = (Ad)\,\Delta p = V\Delta p$$

d = distance over which the pressure drop Δp is measured

A = cross-sectional area on which the force is acting

V = volume of air moved the distance d

Equating the kinetic energy per unit volume (left side of eq. (2)) to one half the work per unit volume gives:

$$1/2\ \rho v^2 = 1/2\ (\frac{V\Delta p}{V}).$$

and

$$v = (\frac{\Delta p}{\rho})^{1/2} \qquad (4)$$

In eq. (4), Δp is the pressure drop, measured from an assumed ambient pressure of 30 inches of mercury, at which v is chosen as zero, because the ambient winds are negligible compared to the winds within a tornado. Since the ambient temperature is about 25°C (77°F), the corresponding ambient air density is equal to 1.19×10^{-3}gm cm^{-3}.

For the assumption of incompressible air, a constant ambient density of 1.19×10^{-3}gm cm^{-3} is substituted for ρ in eq. (4). For the assumption of compressible air, ρ is assumed to decrease dry adiabatically as the pressure decreases. The assumption of incompressibility is sufficiently accurate for comparisons of wind pressure for winds of less than 120 mph. At higher speeds the larger values of windspeeds for the compressible cases (with lower densities), may be closer to the true windspeeds than the values for the incompressible cases.

In the absence of a barometer reading, the static pressure drop can be equated to the vertical pressure drop outside the tornado from the height of the base of the funnel cloud to the base of the low clouds.[3] It is assumed that the mixing ratio (or specific humidity) is spatially invariant, such that the lower edge of the funnel and the low cloud base constitute an isobaric surface with a pressure equal to the condensation pressure.

The method of wind determinations from the minimum static pressure is the least reliable of the three methods, because of uncertainties in the applicability of the simplified Bernoulli equation and in the allowance for loss of kinetic energy.

2.2.3 Synoptic Factors Affecting Storm Intensity and Windspeed

Over the years certain combinations of synoptic parameters have been found to be associated with the most vigorous thunderstorms and tornadoes. Generally a subsidence type inversion is involved separating a low-level moisture tongue from dryer air above.

A narrow band of relatively strong wind flow (jet) is required at all levels and it is extremely desirable for the middle-level and low-level jets to intersect. The optimum height of the wet-bulb temperature of zero degrees is about 8,000 ft. The storms do not develop spontaneously but need some sort of lifting mechanism. A detailed survey by Miller (4) of the specific parameters that play a major role in the production of severe thunderstorms and tornadoes is reproduced in Table 1. This table was compiled from a computer study of 328 tornado cases. Here an attempt was made to define limits on each parameter as required to produce storms of various intensities, and to order the parameters according to importance.

Aside from the above comments, there are several other parameters that must be considered in order to complete the picture. Rates of change of surface temperature, pressure and dew point provide information on regions of decreasing stability and areas where low-level convergence, vertical acceleration and divergence aloft are occurring most rapidly. Difluence at 500 mb and 200 mb not only provides a mass evacuation mechanism aloft but signifies the presence of an approaching positive-vorticity center. Experience has shown that the "level of free convection" should occur at a higher pressure than 600 mb.

Of the parameters discussed above, the following are considered to be the most vital for the development of <u>tornadic</u> storms:

a) Middle and upper level jets with shear zones

b) Low level jet

c) 850 mb maximum temperature field

d) 700 mb dry intrusion

e) Low Sfc pressure

f) High Sfc dew points

The ultimate intensity, therefore is related to the degree to which each of these parameters approaches the critical limits shown in Table 1. If all exceed the specified limits, then one would expect a more severe tornado than if only one-half or more of them did. Tornadoes can and do form in the absence of a jet stream, for instance. However, these are not as severe as those that form in conjunction with a jet stream. In South and Central Florida, the limits required for the jets and the dry-air intrusion at the same time are not reached because of the moderating influences of the water on all three sides of the peninsula.

By definition, the most intense tornado produces the highest vortex windspeeds.

2.2.4 Devastation Statistics and Their Relationship to Windspeeds

Quite obviously the number of deaths and amounts of damage produced by various storms can provide an indirect measure of the severity of the storms in terms of windspeed <u>if</u> information on the population densities and construction in the paths are available. Then one can compare those statistics with the rare windspeed observations of a direct nature, or calculated values using indirect methods, and thereby establish a basis for estimating winds of other storms which occurred during a given historical period.

However, it is extremely difficult to compare the number of deaths or amount of damage caused by a single storm from an earlier period to a recent one because of the problems encountered in normalizing the statistics. It would not be too difficult to normalize population statistics for various years in a given city or state; but the death statistics would still not be valid because of other complicating factors which are far more difficult to assess. For instance, even in 1896, St. Louis was well populated so that if a tornado hit the same sections today, one might expect only a few more deaths from population increases since then; but one would expect fewer deaths after considering the factors of (probably) better warning services and stronger shelter which is not as easily damaged today. The sum total might be fewer deaths from an equal storm today. Despite better building practices, total damages to property would almost certainly be much higher due to the increased value of construction in terms of sophistication, the much greater value due to the shrunken dollar, and the greater number of buildings which might fall in the same path.

It is clear that we should expect roughly the same number of deaths but far greater dollar damage from storms in later years which are actually equal in intensity to their forerunners. The many complicating factors in comparing the statistics of various storms indicate that one must not assign too much weight to small differences in the number of deaths or dollars of damages in assessing the storms' intensities or windspeeds. If, on the other hand, the differences in deaths or damages are an order of magnitude or more, one can be reasonably certain the storms are of significantly different intensities and therefore windspeeds.

TABLE 1

KEY PARAMETERS IN THE PRODUCTION OF SEVERE THUNDERSTORMS AND TORNADOES (after Miller[4])

RANK	PARAMETER		WEAK	MODERATE	STRONG
1	500 mb Vorticity		Neutral or Negative Vort Advection	Contours Cross Vort Pattern <30°	Contours Cross at more than 30°
2	Stability	Lifted Index	-2	-3 to -5	-6
3	Middle Level Jet	Speed Shear	35 knots 15/90 nm	35-50 knots 15-30/90 nm	50 knots 30/90 nm
4	Upper Level Jet	Speed Shear	55 knots 15/90 nm	55 to 85 knots 15-30/90 nm	85 knots 30/90 nm
5	Low-Level Jet Speed		20 knots	25-34 knots	35 knots
6	Low-Level Moisture Mixing Ratio		8 gm H_2O/kg dry air	8 to 12 gm H_2O/kg dry air	12 gm H_2O/kg dry air
7	850-mb Max-Temp Field		E of Moist Ridge	Over Moist Ridge	W of Moist Ridge
8	Winds Cross 700-mb No-Change Line of Advective Temp.		20°	20° to 40°	40°
9	700-mb Dry-Air Intrusion		Not Available - or Available but weak Wind Field	Winds from Dry to Moist Intrude at an Angle of 10 to 40° are at least 15 knots	Winds Intrude at an Angle of 40° and are at least 25 k[illegible].
10	12-hr Sfc Pressure Falls		Zero mb	1 to 5 mb	5 mb
11	500-mb Height Change		30 m	30 to 60 m	60 m
12	Height of Wet-Bulb-Zero above Sfc		Above 11000 ft. Below 5000 ft.	9000 to 11000 ft. 5000 to 7000 ft.	7000 to 9000 ft.
13	Sfc Pressure over Threat Area		1010 mb	1010 to 1005 mb	1005 mb
14	Sfc Dew Point		55°F	55° to 64°F	65°F

nm: nautical miles   m: meters
sfc: surface   mb: millibars

3.0 CONTINENTAL U.S. TORNADOES

Table 2 lists nine tornadoes, of which four are tornadoes of maximum intensity (those with speeds above 321 mph). They are arranged in order of their approximate windspeeds, but since these values are crude, they are grouped according to their central pressure drop in the nearest number of inches of mercury. Within each group, the differences between the listed windspeeds of two or more tornadoes are of no significance. Note that "maximum intensity" refers to the rank according to computed windspeeds. Note also, that the nine storms listed were chosen simply on the basis that certain data were available for them; not because they were all among the nine most intense of the past 115 years. Other storms such as the Palm Sunday tornadoes in 1965; the Waco, Texas tornado in 1953; the Dallas storm in 1957; the Tupelo, Miss. storm in 1936 and other tornadoes could have been cited as examples. However, the last two storms in Table 2 stand out with regard to the number of deaths and the amount of damage produced. The last, the Tri-state tornado of 1925 was quite obviously the most intense from all standpoints.

3.1 The Minneapolis, Minnesota Tornadoes of 20 July 1951 and 20 August 1904

In the outer portion of the first tornado (Minneapolis Airport, July 20, 1951) a minimum sea level pressure of 29.15" Hg. was recorded. It is cited as a verification of the third method. Even with half the kinetic energy dropped, the theoretical windspeed for the compressible case (111 miles/hour) still exceeds the observed fastest mile (92 miles/hour). The agreement is good enough to warrant the use of the third method to obtain approximate windspeeds. Even better agreement is found in the outer part of the other Minneapolis tornado listed (Aug. 20, 1904) [6], in which the pressure drop at the City Office of the Weather Bureau was the same. The wind reached an extreme of 110 miles/hour,[6] almost identical to the theoretical value.

3.2 The Brandon, Ohio Tornado of 20 January 1954

The 28" tornado (Brandon, Ohio, January 20, 1854)[7] shows good agreement between winds of 164 and 173 miles/hour from static and dynamic pressures respectively. The lowest static pressure was 28.21" Hg., whereas the dynamic pressure was that required to account for the breaking of an oak tree.[7]

3.3 The St. Louis Tornado of 27 May 1896 and Washington, Kansas Tornado of 4 July 1932

In the 27" group of tornadoes, the static pressure in the St. Louis tornado of May 27, 1896 was measured by an aneroid barometer in Lafayette Park.[8] When corrected to sea level, it yielded a value of 27.30" Hg. In the Washington, Kansas tornado of July 4, 1932, the dynamic pressure which bent the top of a railroad signal was found to be 110 lbs/ft^2. (The coefficient of 1.6, the same as for tall buildings, was used to calculate the windspeed.)[9]

3.4 The Wallingford, Connecticut Tornado of 9 August 1878

The Wallingford, Connecticut tornado of August 9, 1878 falls in the 26" category of tornadoes because of the high wind required to explain a 2 X 2 X 4 ft. cemetary stone blown off its foundation.(10)

3.5 The Minneapolis Tornado of 20 August 1904; Harrison, Ohio Tornado of 14 February 1854; Worcester, Massachusetts Tornado of 9 June 1953; and Tri-State Tornado of 18 March 1925

The four most severe tornadoes belong in the categories of 24" to 22" Hg. mercury. In the Minneapolis tornado of August 20, 1904, a barometer reading of 23" was obtained.(6) If this was station pressure, the tornado belongs in the 24" category (since the sea level pressure would be nearly one inch higher). If the barometer had been set for sea level pressure, then, of course, the tornado belongs in the 23" category. Since this ambiguity was not resolved, the tornado was listed with the appropriate windspeeds (compressible case) in both pressure categories.

The other two 23" tornadoes were so listed because of their wind pressures. In the Harrison, Ohio tornado of February 14, 1854, a scantling was driven 3 1/2 feet into the ground.(11) The wind in the Worcester, Mass. tornado of June 9, 1953 was obtained from the known load resistance on destroyed towers carrying high voltage lines.(12) The Worcester tornado was the strongest New England tornado on record. This tornado formed in conjunction with a pre-cold-frontal squall line that extended from southern Maine to eastern Connecticut on the afternoon of June 9, 1953. The cold front at that time was gently curving from western Maine through western Massachusetts to central Pennsylvania. Earlier it had passed through the Great Lakes area with widespread tornadic activity in advance of the front. The rhythm was such that on the 7th - 9th violent afternoon activity quickly followed relatively quiescent morning situations. The regeneration of tornadoes on the 9th in the New England area was more pronounced than earlier in the history of the system. Of the several that formed, the one in and around Worcester was the most severe. It killed 90 people and produced $52 million of damage.(14)

The synoptic environment aloft was highlighted by a jet stream at high levels and warm air advection ahead of the squall line at low levels. Slight cooling was evident at middle levels. There was positive vorticity advection aloft in association with the closed-low in southeastern Canada. Hence, most if not all of the synoptic requisites for a severe tornado were present. One can only make inferences regarding synoptic situations aloft for the other storms listed in Table 2 because routine data above the surface were not generally available during those years.

The only tornado reaching the 22" category was the Tri-state tornado, which swept through Missouri, Illinois, and Indiana on March 18, 1925.(13) The best data for determining the wind pressure are from a steel water tank and adjacent concrete chimney of Orient Mine No. 2 at West Frankfort, Illinois. The wind pressure was calculated to be 250 lbs/ft^2, or nearly 1/8 of an atmosphere. The Tri-State tornado of 1925 had a path length of 219 mi, a width of 1,000 to 2,000 yds and traversed predominantly rural areas at a speed of 57 to 68 mph. Had it hit more populous areas both the number of deaths and the damage would have soared even higher for the most intense storm observed in over a century.

TABLE 2

APPROXIMATE WINDSPEEDS OF CONTINENTAL U. S. TORNADOES

(ΔP) 30-(P) (Inches HG)	(P) Central P of Tornado (Inches HG)	Windspeed (miles/hour) Theoretical (Static) Incompressible	Compressible	Determined (Refer to Key)	Date	Place & Reference	Deaths	Damage (Megadollars)
1	29	119	121	92w, 111s (Outer Portion)	7/20/1951	Minneapolis, Minn. (5)	5	6
2	28	169	174	164s, 173d	1/20/1854	Brandon, Ohio (7)	No Data	"Heavy"
3	27	206	214	203s	5/27/1896	St. Louis Mo. (8)	306	12.9
				210d	7/4/1932	Washington, Kan. (9)	5	.5
4	26	238	251	260d	8/9/1878	Wallingford, Conn. (10)	30	.25
5	25	267	285	--	--	--	--	--
6	24	292	316	321s	8/20/1904	Minneapolis, Minn. (6)	14	1.5
7	23	316	348	340d	2/14/1854	Harrison, Ohio (11)	No Data	No Data
				348s	8/20/1904	Minn. Minn. (6)	14	1.5
				343d	6/9/1953	Worcester, Mass. (12)	90	52.0
8	22	337	377	363d	3/18/1925	Murphysboro, Ill. (Tri-State)	689	165

Key to windspeed determinations:

w means observed windspeeds.

d means calculated from dynamic pressure of wind producing structural failure

s means calculated from observed static pressure drop from ambient to tornado center

Note: All dynamic & observed windspeeds include the effect of translation; static windspeeds do not.

4.0 THE FLORIDA TORNADO

Lists of all known tornadoes in Florida east of the Appalachicola River (excluding the panhandle region) have been compiled. One list includes 114 storms from 1887 to 1949 taken mostly from Flora's Tornadoes of the U.S.[15], and Monthly Weather Reviews[16]. The other includes 315 storms from 1950 to 1968 inclusive, all from the "Storm Data and Unusual Weather Phenomena" from the National Summary of Climatological Data, Dept. of Commerce.[17]

Using all known data on each storm including deaths, injuries, damage produced, path length and width, speed of motion, and type of area affected, each of the tornadoes was graded on an intensity scale which included 1 (minimal), 2 (moderate), and 3 (maximal) categories for Florida tornadoes. The results are shown in Table 3 below.

TABLE 3

INTENSITY RATINGS OF 429 FLORIDA TORNADOES

	1887-1949	1950-1968
Minimal	89	273
Moderate	20	36
Maximal	5	6

The two lists were kept separate because of the obvious population and reporting differences which existed during the two periods. One would expect that many minimal storms would have been unreported during the early period; whereas in the later years every waterspout, "waterspout-tornado", "whirlwind", etc., had found its way firmly into the permanent statistics.

The average tornado in Florida is of minimal intensity, barely able to unroof relatively old wooden farm buildings, packing houses and garages, and/or to defoliate, defruit or blow down trees. The "moderate" category was generally reserved for storms which "demolished" or "destroyed" at least one or two normally constructed, wood or stronger buildings, possibly caused personal injuries to a number of people and/or had significant path widths or damage estimates. The maximal category either did significantly greater damage over a larger area, or it appeared from other facts that it would have had it occurred over a suitable area. To assume the most conservative attitude, the three most intense tornadoes in Florida history (82 years) were chosen for comparison with the AEC standard tornado, as probably embodied in the most intense from Table 2, Section 3 above. The three Florida storms occurred on April 5, 1925, June 17, 1959, and April 4, 1966.

No direct measurement of windspeed has been made in a Florida tornado. Indirect calculations have not been presented herein because speeds on the order of 150 to 200 mph could have produced all the damage that has been photographed and tabulated for Florida tornadoes. Attempts are still in progress to locate evidence of speeds higher than this, however, all efforts to date have been unsuccessful. The fact that the

three most severe tornadoes in Florida occurred in or near populous areas prohibits much higher speeds or they certainly would have been documented by the damage.

4.1 The Hialeah Tornado of April 5, 1925

This storm developed early in the afternoon in advance of a cold front that was pushing down the state from a wave-cyclone centered near Jacksonville, Florida. At the time of the tornado, the front extended off the southwest coast near Ft. Myers, Florida. The tornado developed prior to 1:15 P.M. and its motion was toward the northeast at approximately 12 mph. After 20 minutes of progressive movement the tornado stopped and remained stationary for 5 minutes. During this period it rose and descended twice. It then resumed its northeastward motion causing more damage. The total damage was estimated at $.25 million and there were five deaths. Its diameter increased greatly as it passed north of Miami and became obliterated by heavy rain soon afterward. No serious damage was done after that time.

The tornado was preceded by a heavy fall of hail which was confined primarily along the path and in some areas the ground was completely covered with hailstones as large as a baseball. The path of the tornado itself was 12 miles long and slightly less than 100 yards wide.

Upper-air sounding techniques of today were not available in the twenties. As a result, the upper-air structure is not known with any degree of certainty. Since the tornado moved rather slowly, it can be inferred that the steering current was weak and that no divergence or mass evacuation mechanism such as a jet stream existed aloft.

4.2 The Miami Tornado of June 17, 1959

While all eyes were on Tropical Storm Beulah, centered 100 miles northeast of Tampico, Mexico, a tropical depression formed rather unexpectedly in the eastern Gulf near 25.5°N, 86.5°W on the afternoon of June 17, 1959. During the night it deepened and moved northeastward at 35 mph crossing the west coast of Florida just south of Tampa and exiting the east coast just north of Cape Kennedy.

The tornado occurred in Miami at 9:50 P.M. on the 17th. This position was in the right front quadrant approximately 230 n. miles from the center of the deepening depression. Hiser (18) has summarized the eye-witness accounts of the tornado as it moved from the Coconut Grove area of southern Miami skipping over populous areas near downtown Miami, thence down to the ground again in North Miami. The total damage was estimated to be $3 million and no lives were lost. The state climatologist described the storm as the most intense since the 1925 storm. Despite the improved south Florida building codes, neither the total damage nor the loss of life reached the potential that an intense midwestern storm would have produced over such a populated area.

Although there was no major jet stream over South Florida during this period, there may have been a narrow zone or finger of relatively higher wind speeds on the order of 50 knots from Miami to Grand Bahama. Miami reported a wind at 18,000 ft. of 220°/51 knots. At Grand Bahama the winds

above 40,000 ft. were 50 knots or greater. This may have provided some degree of mass evacuation aloft. The tornado moved toward the northeast at 25-28 miles per hour[18]. The Lifted Index was -3.7. The wet-bulb temperature of zero degrees was at 13,000 ft. above M.S.L.

4.3 The Central Florida Tornado of April 4, 1966

A frontal system moved down the state on the 2nd of April and stagnated in South Florida on the 3rd. During the night of the 3rd it washed out and another system moved into the Southeast U. S. trailing a front along the Gulf Coast. The second frontal system moved into the Gulf on the 4th passing through central Florida that night and off the southeast coast during the afternoon of the 5th. Several stable waves formed on that front during its history.

During the morning of the 4th, a tornado formed near Clearwater, Florida and moved east-northeastward across the state to Gibsonia and thence to the Merritt Island area. Another tornado or a family of tornadoes began at Pinellas Point and passed through southern sections of Lakeland, Haines City and thence to Rockledge on a track parallel to the above. Evidence indicates that the northernmost storm maintained continuous contact with the ground from the Gulf to the Atlantic ocean, a distance of 140 miles. The southernmost storm produced an intermittent track as if one tornado lifted and lowered or possibly a family of tornadoes were involved. The northern one was the most severe and produced the most damage of the two. Eleven people were killed, 400 were injured, and property damage was estimated at $11 million. Quite obviously, this was a major storm, probably the largest of Florida record; although no photographs of the funnel(s) have been found because they may have been obscured by precipitation. Considering the nature of this storm and the populated areas traversed by it, it is relatively certain that the damage and deaths were not nearly as great as might have been produced by winds of the order of 300 mph.

This outbreak was associated with a squall line in advance of the frontal system which was located near New Orleans at that time. There was strong convergence aloft at 5,000 ft. with a high-level jet finger of 85 knots oriented WSW-ENE over Tampa. The main jet was over the southeastern U.S. A speed maximum on the order of 60 knots was evident at mid-levels down to at least 10,000 ft. This arrangement of speed maxima aloft is conducive to severe tornadoes, see Table 1. However, there was no indication of strong vorticity advection at 500mb which normally accompanies severe storms. The wet-bulb temperature of zero degrees in this storm was at 13,000 ft. (the same as the '59 tornado), and the Lifted Index on the basis of a partial sounding appeared to be positive.

Proximity soundings showed that while there was a tendency for some drying above 750mb in the 1959 storm, both it and the 1966 tornado soundings were quite moist resembling the Type II Gulf Coast soundings of Fawbush and Miller.[19] Miller[4] states that the Type I sounding is the optimum for severe tornadoes. None of the most severe tornadoes observed in peninsular Florida had Type I air-mass structures. This and certain other key ingredients such as requisite jet maxima, vorticity advection and dry air intrusion have always been missing in varying degrees from even the most severe Florida tornadoes of record.

5.0 COMPARISON OF THE THREE MAXIMAL FLORIDA TORNADOES WITH SEVERE CONTINENTAL U. S. TORNADOES

Flora[14] reports 192 tornadoes in Florida during the years 1916-1949. During this same period, Illinois experienced 190 tornadoes. However, Florida's losses amounted to 31 deaths and 2.4 million dollars property damage while the Illinois losses were 917 deaths and $53.8 million in property damage. The two states are of approximately equal area. The population density per square mile in Illinois was about five times that of Florida. But the Illinois deaths were 30 times larger and damage was more than 22 times greater than Florida's. Flora also listed the outstanding U. S. tornadoes of this period. Several Illinois tornadoes were listed but none for Florida. All of this indicates much less severe tornadoes in Florida than in the midwestern state of Illinois.

Between 1916 and 1958, the average number of people killed per tornado was about nine times higher in the continental U. S. (1.04) than it was in Florida (.12)[13]

In another important tornado publication, Wolford lists the outstanding tornadoes from 1876-1958 for the entire U. S.[13] Again, no Florida storms were included in her listing of 172. Two measures of the intensity of tornadoes used by Wolford include deaths and monetary damage values. Figure 5.1, giving the number of deaths caused by the outstanding storms in Continental U. S., shows clearly that those caused by Florida's most severe would rank her storms in the lowest category of the U. S. outstanding storms. Figure 5.2, showing the damage produced, also tends to confirm the the Florida tornado is not nearly as intense as the most severe storms found elsewhere.

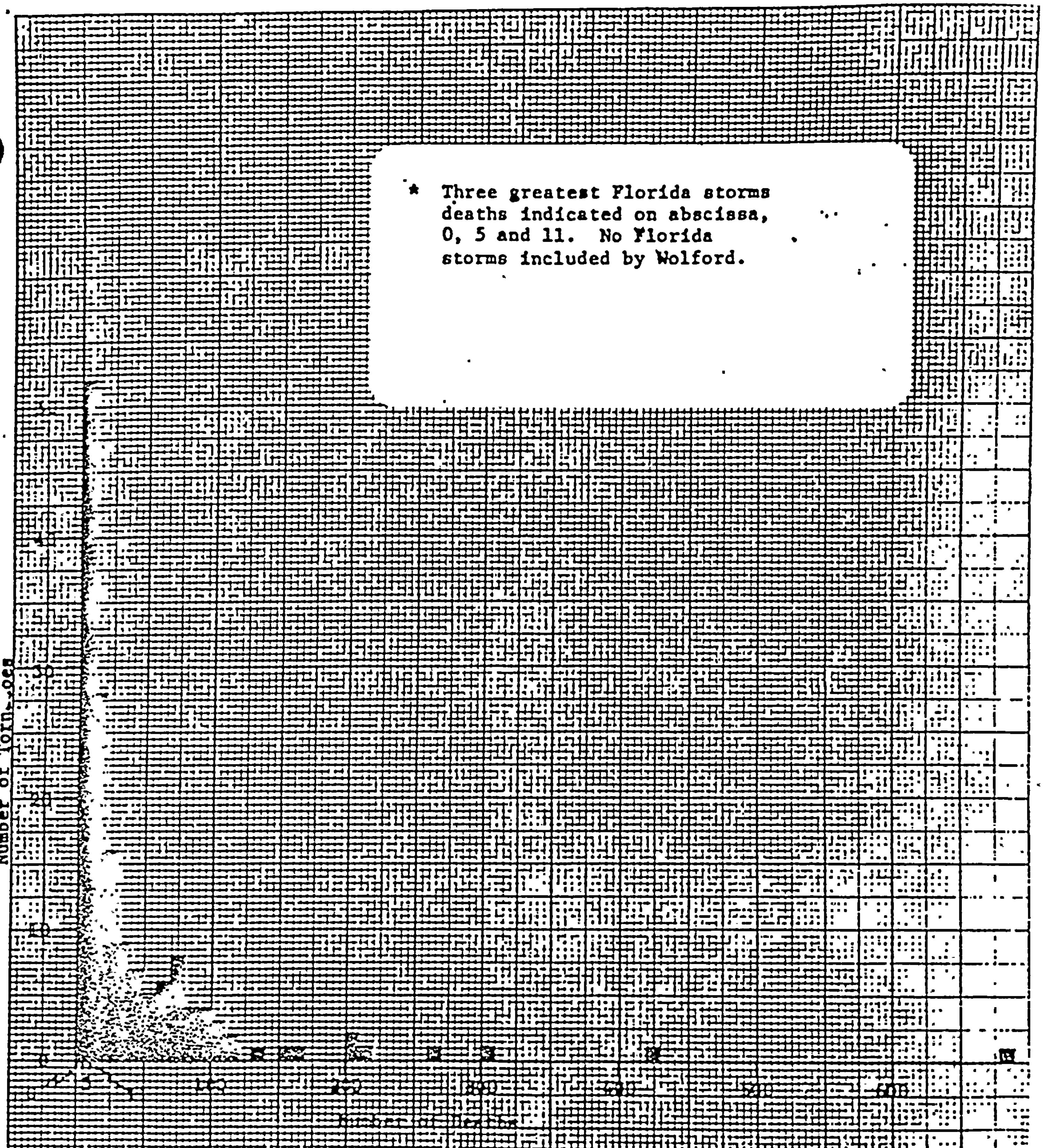
Insofar as tornado intensities and thus windspeeds can be inferred from deaths and damage statistics, it can be shown that continental U. S. storms have considerably higher winds than Florida storms. Evidence presented above shows that there is a greater than order-of-magnitude difference in the statistics for all three of Florida's most severe storms when compared to the most intense of the other continental U. S. tornadoes. Since all three of the severe Florida storms passed over populated areas, in recent years, they had ample opportunity to significantly raise the statistics. The only logical conclusion is that they were not nearly so intense as the most severe continental U. S. tornadoes.

The synoptic environment associated with the three Florida tornadoes was such that several of the key parameters which are generally accepted as being necessary for severe tornadoes, see Section 2.23, were missing. The relatively slow movement of the April 5, 1925 and June 17, 1959 storms indicate that no significant synoptic-scale jet stream existed aloft in those cases. The fast-moving April 4, 1966 tornado did have appropriate wind speeds aloft but they were assocaited with a finger or branch of the main jet which was located in the southeastern United States. Because of the moderating effect of the marine environment around and over peninsular Florida, the dry-air intrusion requirements were not met. Therefore, instability conditions associated with intense storms did not develop. In addition, positive vorticity advection was not indicated in the April 4, 1966 or June 17, 1959 tornadoes. Upper-air charts were not available for the April 5, 1925 storm.

Of the five most severe continental tornadoes for which wind speeds could be determined, Table 2, only one was recent enough to permit both upper-air and surface synoptic analysis. This Worcester, Mass., tornado of June 9, 1953 had the ingredients expected for severe storms as set forth in Table 1 after Miller.

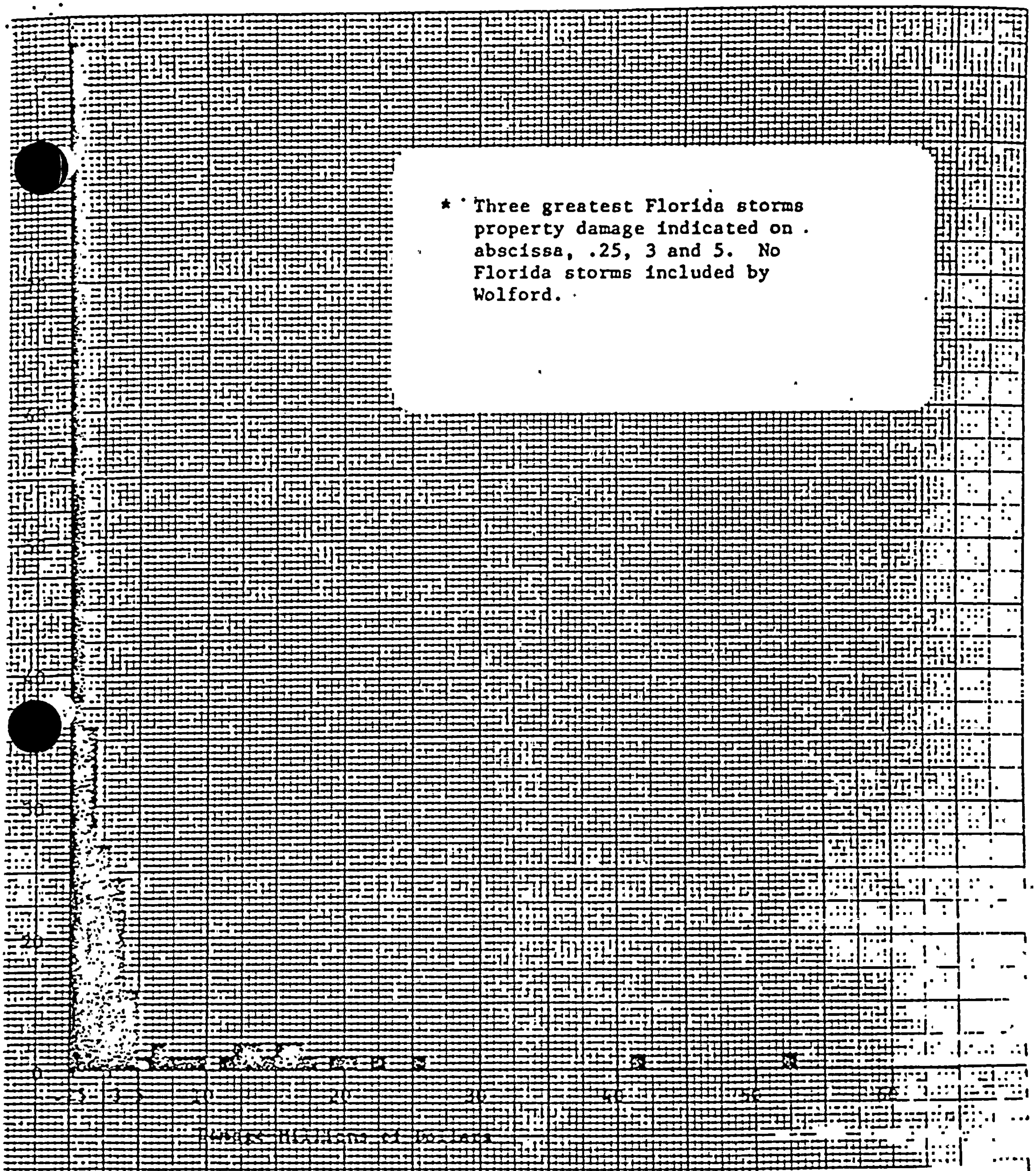
The only reliable direct measurement of windspeed in a tornado was 206 mph in the June 10, 1958 storm at El Dorado, Kansas. This was recorded using Doppler radar. There have been no higher measurements since then. On the basis of indirect measurement, it must be concluded that the most intense continental tornadoes are capable of producing windspeeds on the order of 360 mph which includes effects of translation. The windspeeds calculated upon the basis of static pressures are not as reliable as those calculated from dynamic pressures. The resulting overestimates in the static pressure calculations approximately equal the translation speeds which are included in the dynamic computation. The static value of 377 mph in Table 2 is for a hypothetical 22 inch tornado.

From the standpoint of damage, photographs in Florida do not show buildings being swept clean to the ground and debris carried away as in the most severe continental tornadoes. In no case did the damage substantiate wind speeds exceeding 165 to 200 mph.



FLORIDA POWER & LIGHT COMPANY
HUTCHINSON ISLAND PLANT

DEATHS FROM "OUTSTANDING" TORNADOES OF THE U. S., 1876-1958 (Wolford[20])
FIG. 5-1



FLORIDA POWER & LIGHT COMPANY
HUTCHINSON ISLAND PLANT

DAMAGE FROM "OUTSTANDING" TORNADOES OF THE U. S., 1876-1958 (Wolford[20])
FIG. 5-2

6.0 CONCLUSIONS

It has been shown by calculations from dynamic pressures that the most severe U. S. tornado in the past 115 years had a maximum windspeed of 363 mph which included a translation speed of about 60 mph. Unfortunately, limited observations or calculations were possible for Florida's most intense storms. On the basis of deaths or injuries, and property damage suffered, the most severe tornadoes in Florida history produced less severe effects by a full order of magnitude than the most severe storms which occur in other parts of the continental U. S. No photographs or records of damage have been found to substantiate speeds exceeding approximately 200 mph in Florida tornadoes. In addition, other key ingredients for severe tornadoes such as air-mass structure, jet maxima, vorticity advection, and dry air intrusion, have always been missing in varying degrees in Florida tornadoes. This is a result of Florida's southern latitude and its marine environment.

While it may be possible to produce wind speeds greater than 200 mph (including translation effects) in Florida tornadoes, it is highly unlikely that they would ever reach 300 mph. This upper limit is postulated on the basis that all key synoptic parameters will never simultaneously exist in peninsular Florida and that the order of magnitude difference in damage statistics indicates that higher wind speeds do not occur.

7.0 REFERENCES

(1) Brooks, E.M., 1951, "Tornadoes and Related Phenomena", Compendium of Meteorology, A.M.S., Boston, Mass., pp 673-680.

(2) Smith, R.L., and D.W. Holmes, 1961, "Use of Doppler Radar in Meteorological Observations", Mon. Wea. Rev., Vol. 89, No. 1, pp 1-7.

(3) Ferrel, W., 1893, Popular Treatise on the Winds, Chapter VII, pp 347-350.

(4) Miller, R.C., 1967, Notes on Analysis and Severe-Storm Forecasting Procedures of the Military Weather Warning Center, Tech. Report No. USAR, AWS.

(5) Hovde, M.R., 1952, "The Hennepin County Tornado of July 20, 1951", Weatherwise, Vol. 5, No. 3, June, pp 60-62.

(6) Outram, T.S., 1904, "Storm of Aug. 20, 1904, in Minnesota", Mon. Wea. Rev., August.

(7) Stoddard, O.N., "The Tornado at Brandon, Ohio, Jan. 20, 1854", American Journal of Sciences, Vol. 68, pp 70-79.

(8) Frankenfield, H.C., 1896, "The Tornado of May 27 at St. Louis, Mo.", Mo.Wea. Rev., March.

(9) Marshall, J.D., 1932, "Calculations Regarding Tornado Velocities at Washington, Kansas, July 4, 1932", Bull. of American Meteor. Soc., August.-Sept., p 149.

(10) Hazen, H.A., 1890, "Facts about Tornadoes", Science, Vol. 16, August, pp 58-62.

(11) Stoddard, O.N., "The Tornado at Harrison, Ohio, Feb. 14, 1854", American Journal of Science, Vol. 70, No. 161.

(12) Booker, C.A., 1953, "Tower Damage Provides Key to Worcester Tornado Data", Electric World, N.Y., Vol. 140, No. 7, pp 22-24.

(13) Western Society of Engineers, Committee, 1925, "Report on Effects of Tornado of March 18, 1925, also Sugestions in Regard to Design of Structures", Western Society of Engineering Journal, Vol. 30, No. 9, September, pp 373-396.

(14) Wolford, L.V., 1960, Tornado Occurrences in the United States, Tech. Paper No. 20, U.S.W.B., 71pp.

(15) Flora, Snowden, 1954, Tornadoes of the United States, University of Oklahoma Press, March, 221pp.

(16) U.S.W.B., Dept. of Commerce, Monthly Weather Reviews for the period 1871-1949.

(17) U.S.W.B., Dept. of Commerce, "Storm Data and Unusual Weather Phenomena", National Summary of Climatological Data, 1950-1968.

(18) Hiser, H. W., 1968, "Radar and Synoptic Analysis of the Miami Tornado of June 17, 1959", J. Appl. Meteor., Vol. 7, No. 5, pp 892-900.

(19) Fawbush, E.J., and R.C. Miller, 1954, "The Types of Airmasses in Which North American Tornadoes Form", Bull. Amer. Meteor. Soc., Vol. 35, No. 4, pp 154-165.

APPENDIX 2F

THE DESIGN BASIS TORNADO FOR THE ATLANTIC COAST AND FLORIDA'S EAST COAST

I. TORNADO DESIGN CRITERIA

An analysis of all tornadoes occurring along the Atlantic coast recorded in Storm Data for the period 1950 to 1972 is given in paragraph II. A Design Tornado was developed in parallel with the methodology presented in "Technical Basis for Interim Regional Tornado Criteria."[1]

1.	Maximum speed	=	218 mph
2.	Tangential wind speed (rotational)	=	163 mph
3.	Translational wind speed, maximum	=	55 mph
	minimum	=	5 mph
4.	Pressure drop at center of vortex	=	.944 psi
5.	Maximum rate of pressure drop	=	.508 psi/sec

II. BASIS FOR SELECTION OF DESIGN TORNADO

The development of a "design tornado" follows the probabilistic approach proposed by the AEC which results in the probable 10^{-7} per year wind speed.[1] In this investigation, the 10^{-7} per year Design Tornado is determined for the Atlantic Coastal region. All tornadoes reported in Storm Data (and confirmed by the N.S.S.F.C. logs between 1950 and 1972) which occurred within 4 miles of the Atlantic Coast, or within the Florida Keys were included.

assification of intensity was made using an objective guide based upon the ames & Moore Intensity Scale described in Section III given sufficient etail from either Storm Data or the American Red Cross and news clippings. Similarly, the area of each tornado was determined from path length and width data.

The geometric probability is given by

$$P = n(a/A)$$

when P = mean annual probability of a tornado striking a point

n = mean number of tornadoes occurring with the area A per year

a = average path length X path width

The values used for the Atlantic Coast are as follows:

Atlantic Coast

a	$0.257\ mi^2$
A	$16,100\ mi^2$
n	$9.0\ yr^{-1}$
P	$1.44 \times 10^{-4}\ yr^{-1}$

10^{-7} wind speed

Since Florida had by far the largest sample of tornadoes, the average tornadic area (P_l X P_w) found for Florida was used for the Atlantic coast. The value of "a" from Florida was the highest of the average areas of all the Atlantic States and it is therefore a conservative assumption. The geometric annual probability of any tornado striking a point is coupled with the probability of a given intensity to yield the probable 10^{-7} (per year) wind speed. The resulting value for the Atlantic coast is 218 mph.

It is felt that the departure of the intensity frequencies from a log-normal distribution is more than adequately compensated for by using the upper bound of the intensity interval. Also, it is likely that a bias exists in the reporting of tornado events. This results primarily in an under-reporting of unseen or less damaging tornadoes which would probably fall into the D&M1 and D&M 2 categories and reduce the slope of the curves shown in Figure 1.

Little recorded data was found on translational wind speed in the regions of interest. Flora[2], for example, states that 45 mph is the average translation wind speed based upon a study of 1,000 tornadoes by J.R. Martin[2] and Wolford [3] states that 40 mph is the average for all tornadoes. A general opinion among severe weather meteorologists is that tornadic intensity is correlated (indirectly) with translational speed. This is due to the fact that intense storms are associated with strong jets in the mid-levels of the troposphere which in turn propels the parent cloud in proportion to the average wind speed of the cloud layer[4]. This is supported by a study of long track ($\geq$ 100 mi. path lengths) tornadoes which are very intense tornadoes and have an average translational speed of 67.8 mph[5].

The Design Basis Tornado parameters are shown below.

Max. Speed (mph)	Rotational Speed (mph)	Translational Speed (mph)		Total Pressure Drop (Psi) Δp	Maximum Rate of Pressure Drop (psi/sec)
		Max.	Min.		
218	163	55	5	.944	.508

The maximum rate of pressure drop occurs at the radius of maximum wind and is determined by:

$$\frac{dp}{dt} = \rho_A \frac{V_m^2 T}{r_m} \quad \text{where}$$

p = pressure

t = time

T = translational speed

r_m = radius of maximum rotational windspeed - 150'

V_m = maximum tangential wind

The total pressure drop, Δp, is determined by:

$$\int_0^r \frac{\partial p}{\partial r}\, dr = \int_0^r 2\rho_A \frac{V_m^2}{r_m}\, dr$$

the application of the cyclostrophic wind equation.

The maximum value of 218 mph is consistent with the previous studies conducted by Florida Power and Light where the maximum tornadic wind is seen from damage estimates to be in the range of 165 to 200 mph[6].

The Design Tornado for the Atlantic Coast is less than that determined by the AEC for Region 1. This results from the following:

(1) The geometric probability is less using the actual path length and width of the region under consideration. The average area of these tornadoes is an order of magnitude less than Iowa tornadoes, .26 mi^2 vs. 2.82 mi^2.

(2) Some of these coastal tornadoes are actually "tornadic waterspouts" or have been induced by hurricanes and are seldom intense due to the lack of strong vertical shear of the horizontal wind through a deep layer of the atmosphere. This shear is essential to the explosive development of large rotating thunderstorms which spawn severe tornadoes.[7,8,9]

(3) The D&M Inteisity Scale is based upon extensive analysis of the effects of wind loadings upon structures such that an objective estimate of wind speed may be made from written summaries of damage accounts. Although a comparative study has yet to be made, it is likely that differences exist between the D&M Intensity classification and the F-Scale classification.

III DAMES & MOORE INTENSITY SCALE

Dames & Moore tornadic wind intensity scale was created in order to evaluate tornado damage and associated causative wind speeds. In development of this scale, it was necessary to calculate the range of wind speeds which could conceivably give rise to reported structural damage. Probable wind velocities were estimated from observed damage and these velocities were used to classify tornadoes according to intensity. The results of these evaluations permitted a reasonable classification of tornadoes according to wind velocity-damage relationships which are in general agreement with other attempts [10].

Several assumptions were necessary in order to evaluate the wind velocities associated with varying damage of residences and other buildings. Construction variances resulting from differences in local codes and workmanship and quality of construction were accounted for in the calculation of the range of wind velocities associated with particular types and extents of damage. Due to the extent of these variations, a fairly wide range of overlapping wind velocities is given for each type of damage.

Specific assumptions were employed regarding the action of wind forces on the building. A sustained peak wind velocity was considered. Gusting effects, repeated loadings, and racking of structural members and joints were not included. The effects of rapid decrease in air pressure on the structure were disregarded since natural venting through broken windows, damaged siding, etc. minimizes or negates the pressure drop effects and few such cases were observed in the tornado record. The wind pressure coefficients utilized in the structural calculations were selected from the American National Standard Building Code, 1972.[11] Various sizes and numbers of connectors were assumed for the roof to wall connections, thus yielding a range of wind velocity values associated with varying roof damage levels. Calculations were made to verify the wind forces required to inflict these levels of damage, for partial or total roof removal.

The specific results of the above mentioned calculations are reflected in Table I entitled "Dames & Moore Tornado Intensity Classification." Progressively higher degrees of damage are summarized in the damage description for Dames & Moore Intensity categories 1 through 6. Each category has an associated velocity range which is the sum of the rotational and translational speeds.

The major source of damage description was obtained from the N.S.S.F.C. records and Storm Data. This information was supplemented by data obtained from the American Red Cross and some newspaper articles. In classifying the tornadoes, engineering estimates were based predominately on the highest degree of damage occurring in the description. If the available damage description was inadequate or nonexistent, the tornado path length and width, the dollar damage category and the geographic location were considered in assigning the appropriate damage intensity. However, in some instances, the information available from the Storm Data or American Red Cross was insufficient for classification in accordance with the Dames & Moore Intensity guidelines and, therefore, that tornado was not analyzed.

The application of these guidelines to the Atlantic states is given in Table II.

IV. FLORIDA EAST COAST ANALYSIS

A separate analysis of tornadoes occurring within the four mile inland coastal strip of the Florida Atlantic Coast is provided. All reported tornadoes which originated, terminated or crossed the four mile coastal strip are included in this analysis. However, the computed tornado affected areas (path length and width) are only restricted by an upper path limit of 10 miles. The methodology is identical to the one described in the previous sections except only tornado occurrences indigenous to the Florida east coast are analyzed.

Table III summarizes the climatological tornado data of the Florida east coast by year of occurrence and county. During the period 1950 to 1960, 34 tornadoes were sighted. However, during the period 1960 to 1970, 67 tornadoes were sighted. Comparing the two decades of time, the number of tornado reports increased by 97%. The population increase for the east coast of Florida (documented in Table IV) from 1950 to 1970 was 183%. If climatological tornado trends are discounted, there appears to be a correlation between increasing tornado reports and increasing population densities. Intense tornadoes, however, normally affect a large area[5] and the tornado sightings should be independent of population density in an already populous region. Many low intensity tornadoes may have been undetected or not reported in the earlier portion of the sampling period. The increase in the tornado-affected area ('a' term in the geometric probability equation) associated with unreported low intensity tornadoes is small as compared to more intense reported tornado occurrences.

As previously defined:

$$P = n(a/A)$$

where:

$a = 0.257$ miles^2 (for Florida East Coast)

$A = 2420$ miles^2 (area examined)

$n = 112/23$ (1950 to 1972)

$P = 5.17 \times 10^{-4}$ yr^{-1}

Table V summarizes the Florida East Coast tornadoes by the Dames & Moore upper class intensity scale. Figure 2 is derived from the data in Table V. To determine the extrapolated percent probability with the associated maximum wind speed for the one in ten million probability:

$$\frac{P \text{ of } 1.0 \times 10^{-7}}{P \text{ for Florida East Coast}} = 0.193 \times 10^{-3} = 0.019\%$$

and the associated maximum wind speed, from Figure 2, is 242 mph for 1.0×10^{-7} probability level.

Detailed information on the tornadoes under study is provided herein. Table VI gives the chronological list of tornadoes for the period of 1950-1972 and the available path lengths, widths and areas. Table VII classifies these tornadoes into the Dames & Moore intensity categories. The tornadoes are tabulated according to damage description in each intensity category. The miscellaneous category includes the damage descriptions listed in Table I which are not separately described in this table.

For purposes of summarizing the Florida East Coast tornado intensity classification, Table VIII has been prepared. It should be pointed out that for tornadoes where the area data is not available the average area was assumed for purposes of this analysis (See note 2, Table VIII).

1. Technical Basis for Interim Regional Tornado Criteria, WASH-1300 (UC-11), U.S.A.E.C. Office of Regulation, May, 1974.

2. Flora, S.D., Tornadoes of the United States, University of Oklahoma Press, Norman, Oklahoma, pp. 194., 1954, 2nd edition

3. Wolford, L.V., Tornado Occurrences in the U.S., USWB Tech Paper No. 20, 1960

4. Wilson, J.W., "Movement and Predictability of Radar Echoes", ERCTM-NSSL-28, Norman, Oklahoma, November, 1966

5. Wilson, J.W. and Morgan, G.N., "Long-Track Tornadoes and Their Significance", Preprints. Seventh Conference on Severe Local Storms, A.M.S., Kansas City, Missouri, October 5-7, 1971

6. Brooks, E.M., Gerrish, H.P., Hiser, H.W. and Senn, H.V., "A Comparative Study of Florida's Most Severe Tornadoes with Those in other Parts of the Continental U.S.", Docket No. 50-335, Fla. Power and Light Company, Miami, Florida

7. Newton, C.W., 1950 "Structure and Mechanism of the Prefrontal Squall Line", J. Meteorology, Vol. 7, No. 3, pp. 210-222

8. Ward, N.B., "Rotational Characteristics of a Tornado Cyclone", Preprints, Sixth Conference on Severe Local Storms, A.M.E., Chicago, Illinois, October, 1969

9. Nicholson, F.H., "The Formation of Severe Local Storms Through the Agency of Random Turbulent Transport", Preprints, Eighth Conference on Severe Local Storms, A.M.S., Denver, Colorado, October 15-17, 1973

10. Fujita, T.T., "Proposed Characterization of Tornadoes and Hurricanes by Area and Intensity", Chicago University, Department of Geophysical Sciences, Satellite and Mesometeorology Research Project, Research Paper No. 91, February 1971.

11. "American National Standard Building Code Requirements for Minimum Design Loads in Buildings and Other Structures", American National Standards Institute, New York, New York, A58.1 - 1972

TABLE I

DAMES AND MOORE

TORNADO INTENSITY CLASSIFICATION

DAMES & MOORE INTENSITY	WIND VELOCITY (mph)	EXPECTED DAMAGE
1	50-90	Partial roof removal of weak rural structures; some trees uprooted and blown
2	80-120	Total roof removal of rural structures; partial roof removal of individual residences; house trailers moved or rolled; more extensive tree uprooting
3	100-150	Rural structures heavily damaged; total roof removal of residences; house trailers destroyed; nonreinforced masonry walls overturned; extensive sign damage and tree uprooting
4	120-180	Rural structures demolished; total roof removal of residences and some walls down; partial roof removal of light steel industrial buildings and wood truss commercial buildings.
5	150-225	Complete homes destroyed; total roof removal of light industrial buildings and wood truss commercial buildings; partial roof removal of heavy industrial buildings
6	200-300	Catastrophic destruction; homes off foundations; substantial commercial and industrial buildings destroyed; large steel framed structures heavily damaged.

TABLE II
TORNADOES AND THEIR INTENSITIES
OCCURRING ALONG THE ATLANTIC COAST

FROM 1950 - 1972

Dames & Moore Intensity Class	FLA.E COAST	GA.	SC.	NC.	VA.	MD.	NJ.	MASS.	ME.	Total Classified By Intensity	Adjusted Total For All Tornadoes
6	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
4	9	0	1	3	0	1	0	0	0	14	15.8
3	11	1	2	7	1	2	2	0	0	26	29.2
2	47	2	4	7	5	2	1	4	1	73	82.1
1	31	4	11	5	6	6	2	3	3	71	79.9
TOTAL	98	7	18	22	12	11	5	7	4	184	207
All Tors	112	7	20	25	12	11	6	10	4	207	

TABLE III

TORNADO SIGHTING ALONG THE 4 MILE ATLANTIC INLAND SHORELINE FOR EAST COAST FLORIDA COUNTIES BY YEAR

Counties

Year	Nassau	Duval	St. Johns	Flagler	Volusia	Brevard	Indian River	St. Lucie	Martin	Palm Beach	Broward	Dade	Totals
1950				1									1
51													0
52										2			2
53						1		2				1	4
54						1		2				1	4
55										1	2		3
56									1	1		1	3
57													0
58			1			1				4			6
1959			1		1	1			1	1	1	1	7
60					2			1		1			4
61	1	1						1		1			4
62			1					1		1		1	4
63					1	1	1			1			4
64			1	1	1	2			1	4		1	11
65										1	2		3
66						3	1					2	6
67						1		1		2	1		5
68					2	7				4		4	17
1969					1						1	2	4
70	1				1	2		1	1	2		1	9
71						3				1	1	1	6
1972		1				6				1	1		9
Totals	2	2	4	2	9	29	2	9	4	28	9	16	116

TABLE IV

POPULATION IN COASTAL FLORIDA COUNTIES

U.S. BUREAU OF CENSUS

	1950	1970
Dade	495,084	1,267,792
Broward	83,933	620,100
Palm Beach	114,688	348,753
Martin	7,807	28,035
St. Lucie	20,180	50,836
Indian River	11,872	35,992
Brevard	23,653	230,006
Volusia	74,229	169,487
Flagler	3,367	4,454
St. John's	24,998	30,727
Duval	304,029	528,865
Nassau	12,811	20,626
Totals	1,176,651	3,335,673

TABLE V

COASTAL EAST FLORIDA TORNADOES

FROM 1950 TO 1972

Dames & Moore Intensity Class	Florida East Coast	Adjusted Total For All Tornadoes	Cumulative Frequency m	Cumulative Percent $\left(1 - \frac{m}{112 + 1}\right)$ Times 100	Dames & Moore Upper Class Wind Speed mph
6	0	0			300
5	0	0			225
4	9	10.3	112.0	0.88	180
3	11	12.6	101.7	10.00	150
2	47	53.7	89.1	21.15	120
1	31	35.4	35.4	68.67	90
Subtotal	98	112.0			
Unknown	14	0			
Total	112	112.0			

TABLE VI

Tornado Statistics for the East Florida Coast

Reference: Storm Data; NOAA

Period of Record 1950 to 1972

Number	Year	Month	County	Length (Miles)	Width (Yards)	Width (Miles)	Area (Sq. Miles)
1	1950	March	Flagler		150		
2	1952	February	Palm Beach	1.5	15	.009	.014
3	1952	August	Palm Beach	.17	15	.009	.002
4	1953	April	St. Lucie	2.0			
5	1953	August	St. Lucie				
6	1953	September	Brevard	1.0	200	.114	.114
7	1953	September	Dade				
8	1954	April	Dade				
9	1954	August	St. Lucie				
10	1954	September	St. Lucie				
11	1954	September	Brevard		90		
12	1955	April	Broward				
13	1955	August	Palm Beach				
14	1955	October	Broward				
15	1956	August	Palm Beach				
16	1956	August	Martin				
17	1956	October	Dade				
18	1958	January	Brevard				
19	1958	April	St. John's	3.0	75	.043	.129
20	1958	April	Palm Beach				
21	1958	April	Palm Beach				
22	1958	August	Palm Beach				
23	1958	August	Palm Beach				
24	1959	April	Brevard	1.0	100	.057	.057
25	1959	June	St. John's				
26	1959	June	Dade	10(12.0)	350	.199	1.99
27	1959	June	Palm Beach	7.0	150	.085	.595
28	1959	September	Broward		33		
29	1959	October	Volusia	1.0	70	.040	.040
30	1959	October	Martin				

TABLE VI (Con't)

Tornado Statistics for the East Florida Coast

Reference: Storm Data; NOAA

Period of Record 1950 to 1972

Number	Year	Month	County	Length (Miles)	Width (Yards)	Width (Miles)	Area (Sq. Miles)
31	1960	July	Volusia				
32	1960	July	Volusia				
33	1960	September	Palm Beach				
34	1960	October	St. Lucie				
35	1961	March	Nassau				
36	1961	April	Duval				
37	1961	May	Palm Beach				
38	1961	June	St. Lucie				
39	1962	July	St. Lucie				
40	1962	August	St. John's				
41	1962	September	Palm Beach				
42	1962	November	Dade	1.0			
43	1963	July	Palm Beach				
44	1963	July	Brevard				
45	1963	August	Volusia				
46	1963	November	Indian River				
47	1964	August	Brevard				
48	1964	August	St. John's				
49	1964	August	Flagler				
50	1964	August	Volusia				
51	1964	October	Dade		75		
52	1964	October	Palm Beach				
53	1964	October	Palm Beach				
54	1964	October	Martin				
55	1964	October	Palm Beach				
56	1964	October	Palm Beach				
57	1964	October	Brevard				
58	1965	February	Broward	5.0	60	.034	.170
59	1965	February	Broward	15.0			
60	1965	March	Palm Beach				
61	1966	April	Brevard	10(14.0)	350	.199	1.99

TABLE VI (Cont'd)

Tornado Statistics for the East Florida Coast

Reference: Storm Data; NOAA

Period of Record 1950 to 1972

Number	Year	Month	County	Length (Miles)	Width (Yards)	Width (Miles)	Area (Sq. Miles)
62	1966	April	Brevard		150		
63	1966	June	Dade	4.0			
64	1966	June	Dade				
65	1966	June	Indian River				
66	1966	September	Brevard				
67	1967	February	Broward				
68	1967	June	Palm Beach				
69	1967	August	St. Lucie				
70	1967	August	Brevard				
71	1967	September	Palm Beach				
72	1968	February	Dade	4.5	100	.057	.257
73	1968	February	Palm Beach				
74	1968	May	Brevard				
75	1968	June	Brevard	0.3			
76	1968	June	Brevard	0.1	15	.009	.001
77	1968	June	Dade				
78	1968	June	Brevard				
79	1968	June	Dade	10.0			
80	1968	July	Brevard				
81	1968	July	Palm Beach				
82	1968	August	Volusia	5.0			
83	1968	August	Volusia	2.0	125	.071	.142
84	1968	September	Brevard	1.5			
85	1968	October	Dade		800		
86	1968	October	Palm Beach				
87	1968	November	Brevard	.25	200	.114	.029
88	1968	November	Palm Beach	8.0	30	.017	.136
89	1969	February	Dade	1.0	125	.071	.017
90	1969	June	Dade				
91	1969	August	Broward				
92	1969	October	Volusia				
93	1970	January	St. Lucie				

TABLE VI (Cont'd)

Tornado Statistics for the East Florida Coast

Reference: Storm Data; NOAA

Period of Record 1950 to 1972

Number	Year	Month	County	Length (Miles)	Width (Yards)	Width (Miles)	Area (Sq. Miles
94	1970	February	Brevard				
95	1970	March	Brevard	1.9	333	.189	.359
96	1970	March	Dade				
97	1970	March	Palm Beach				
98	1970	June	Martin				
99	1970	July	Nassau				
100	1970	July	Volusia				
101	1970	July	Palm Beach				
102	1971	February	Palm Beach	.057	.10	.006	0(.0005)
103	1971	June	Broward	4.0	50	.028	.112
104	1971	June	Dade	2.0	200	.114	.228
105	1971	August	Brevard	3.0	75	.043	.129
106	1971	August	Brevard	3.0	25	.014	.042
107	1971	September	Brevard	0.25	20	.011	.003
108	1972	February	Brevard				
109	1972	March	Brevard	2	500	.284	.568
110	1972	March	Brevard	1	100	.057	.057
111	1972	March	Brevard	2	50	.028	.056
112	1972	June	Brevard	0.25	50	.028	.007
113	1972	June	Brevard	2	100	.057	.114
114	1972	June	Brevard	4	100	.057	.228
115	1972	June	Brevard	3	100	.057	.171
116	1972	July	Duval	0.25	30	.017	.004

TABLE VII

STORM DATA DAMAGE REPORTS
FOR PERIOD OF RECORD: 1950 TO 1972

Dames & Moore Intensity Categories

Wind Speed Range (mph)	1		2			3			4			5			6	
	50-90	Misc.	80-120		Misc.	100-150		Misc.	120-180		Misc.	150-250		Misc.	225-300	Misc.
Chronological Listing	Trees Downed and Uprooted		Partial Roof	Small Buildings Damage		Total Roof	Partial Home Damage		Severe Home Damage	Weak Structures Flatten		Homes Destroyed	Substantial Buildings Damaged		Substantial Buildings Destroyed	
1					X											
2					X											
3				X												
4		X														
5		X														
6		X														
7		X														
8		X														
9		X														
10				X												
11					X											
12					X											
13																
14				X												

TABLE VII (Con't)

STORM DATA DAMAGE REPORTS
FOR PERIOD OF RECORD: 1950 TO 1972

Dames & Moore Intensity Categories

Wind Speed Range (mph)	1 50-90 Misc.		2 80-120 Misc.		3 100-150 Misc.		4 120-180 Misc.		5 150-250 Misc.	6 225-300 Misc.
Chronological Listing	Trees Downed and Uprooted	Partial Roof	Small Buildings Damage	Total Roof	Partial Home Damage	Severe Home Damage	Weak Structures Flatten	Homes Destroyed	Substantial Buildings Damaged	Substantial Buildings Destroyed
15	X									
16	X									
17			X							
18	X									
19						X	X			
20	X									
21	X									
22	X									
23	X									
24						X	X			
25	X									
26							X			
27		X	X							
28	X									

2F-21

Rev. 36 - 12/20/74

TABLE VII (Con't)

STORM DATA DAMAGE REPORTS
FOR PERIOD OF RECORD: 1950 TO 1972

Dames & Moore Intensity Categories

Wind Speed Range (mph)	1 50-90 Misc.	2 80-120 Misc.		3 100-150 Misc.		4 120-180 Misc.		5 150-250 Misc.		6 225-300 Misc.
Chronological Listing	Trees Downed and Uprooted	Partial Roof	Small Buildings Damage	Total Roof	Partial Home Damage	Severe Home Damage	Weak Structures Flatten	Homes Destroyed	Substantial Buildings Damaged	Substantial Buildings Destroyed
29			X							
30										
31	X									
32										
33	X									
34			X							
35					X					
36			X							
37	X									
38										
39			X							
40			X							
41										
42			X							

TABLE VII (Con't)

STORM DATA DAMAGE REPORTS
FOR PERIOD OF RECORD: 1950 TO 1972

Dames & Moore Intensity Categories

Wind Speed Range (mph)	1		2		3		4		5	6
	50-90 Misc.		80-120 Misc.		100-150 Misc.		120-180 Misc.		150-250 Misc.	225-300 Misc.
Chronological Listing	Trees Downed and Uprooted	Partial Roof	Small Buildings Damage	Total Roof	Partial Home Damage	Severe Home Damage	Weak Structures Flatten	Homes Destroyed	Substantial Buildings Damaged	Substantial Buildings Destroyed
43			X							
44	X									
45	X									
46			X							
47	X									
48										
49			X							
50										
51	X									
52	X									
53			X							
54	X									
55	X									
56			X							

TABLE VII (Con't)

STORM DATA DAMAGE REPORTS
FOR PERIOD OF RECORD: 1950 TO 1972

Dames & Moore Intensity Categories

Wind Speed Range (mph)	1 50-90	Misc.	2 80-120	Misc.	3 100-150	Misc.	4 120-180	Misc.	5 150-250	Misc.	6 225-300	Misc.
Chronological Listing	Trees Downed and Uprooted		Partial Roof	Small Buildings Damage	Total Roof	Partial Home Damage	Severe Home Damage	Weak Structures Flatten	Homes Destroyed	Substantial Buildings Damaged	Substantial Buildings Destroyed	
57						X						
58						X						
59					X	X						
60				X								
61						X						
62					X	X						
63				X								
64												
65												
66												
67		X										
68				X								
69				X								
70				X								

TABLE VII (Con't)

STORM DATA DAMAGE REPORTS
FOR PERIOD OF RECORD: 1950 TO 1972

Dames & Moore Intensity Categories

Wind Speed Range (mph) / Chronological Listing	1: 50-90 Trees Downed and Uprooted	1: Misc.	2: 80-120 Partial Roof	2: Small Buildings Damage	2: Misc.	3: 100-150 Total Roof	3: Partial Home Damage	3: Misc.	4: 120-180 Severe Home Damage	4: Weak Structures Flatten	4: Misc.	5: 150-250 Homes Destroyed	5: Substantial Buildings Damaged	5: Misc.	6: 225-300 Substantial Buildings Destroyed	6: Misc.
71								X								
72									X	X	X					
73					X											
74																
75					X											
76																
77					X											
78					X											
79					X											
80					X											
81					X											
82					X											
83							X	X								
84			X	X	X											

2F-26

Rev. 36 - 12/20/74

TABLE VII (Con't)

STORM DATA DAMAGE REPORTS
FOR PERIOD OF RECORD: 1950 TO 1972

Dames & Moore Intensity Categories

Wind Speed Range (mph)	1 50-90		2 80-120			3 100-150			4 120-180			5 150-250			6 225-300	
Chronological Listing	Trees Downed and Uprooted	Misc.	Partial Roof	Small Buildings Damage	Misc.	Total Roof	Partial Home Damage	Misc.	Severe Home Damage	Weak Structures Flatten	Misc.	Homes Destroyed	Substantial Buildings Damaged	Misc.	Substantial Buildings Destroyed	Misc.
85		X														
86						X		X								
87				X	X											
88								X								
89					X											
90																
91				X												
92		X														
93				X												
94				X												
95									X	X						
96				X												
97	X	X														
98				X												

TABLE VII (Con't)

STORM DATA DAMAGE REPORTS
FOR PERIOD OF RECORD: 1950 TO 1972

Dames & Moore Intensity Categories

Wind Speed Range (mph)	1		2			3			4			5			6	
	50-90	Misc.	80-120		Misc.	100-150		Misc.	120-180		Misc.	150-250		Misc.	225-300	Misc.
Chronological Listing	Trees Downed and Uprooted		Partial Roof	Small Buildings Damage		Total Roof	Partial Home Damage		Severe Home Damage	Weak Structures Flatten		Homes Destroyed	Substantial Buildings Damaged		Substantial Buildings Destroyed	
99		X														
100		X														
101				X												
102																
103			X	X	X											
104				X	X											
105								X								
106					X											
107					X											
108		X														
109									X							
110								X								
111							X	X								
112		X														
113									X	X						
114										X	X					
115									X	X						
116		X														

TABLE VIII

TORNADO INTENSITY CLASSIFICATION

Dames & Moore Intensity Class	Wind Speed (MPH) (1)	Number of Classified Tornadoes	Number After Adjustment (2)
1	50-90	34	38.7
2	80-120	46	52.3
3	100-150	13	14.8
4	120-180	9	10.2
5	150-225	0	0
6	200-300	0	0

(1) Each tornado is assumed to have the maximum possible wind speed for the Dames and Moore intensity class to which it has been assigned.

(2) Since fourteen (14) tornadoes were of unknown intensity although reported, the last column reflects those 14 distributed proportionately to those which were classified by intensity.

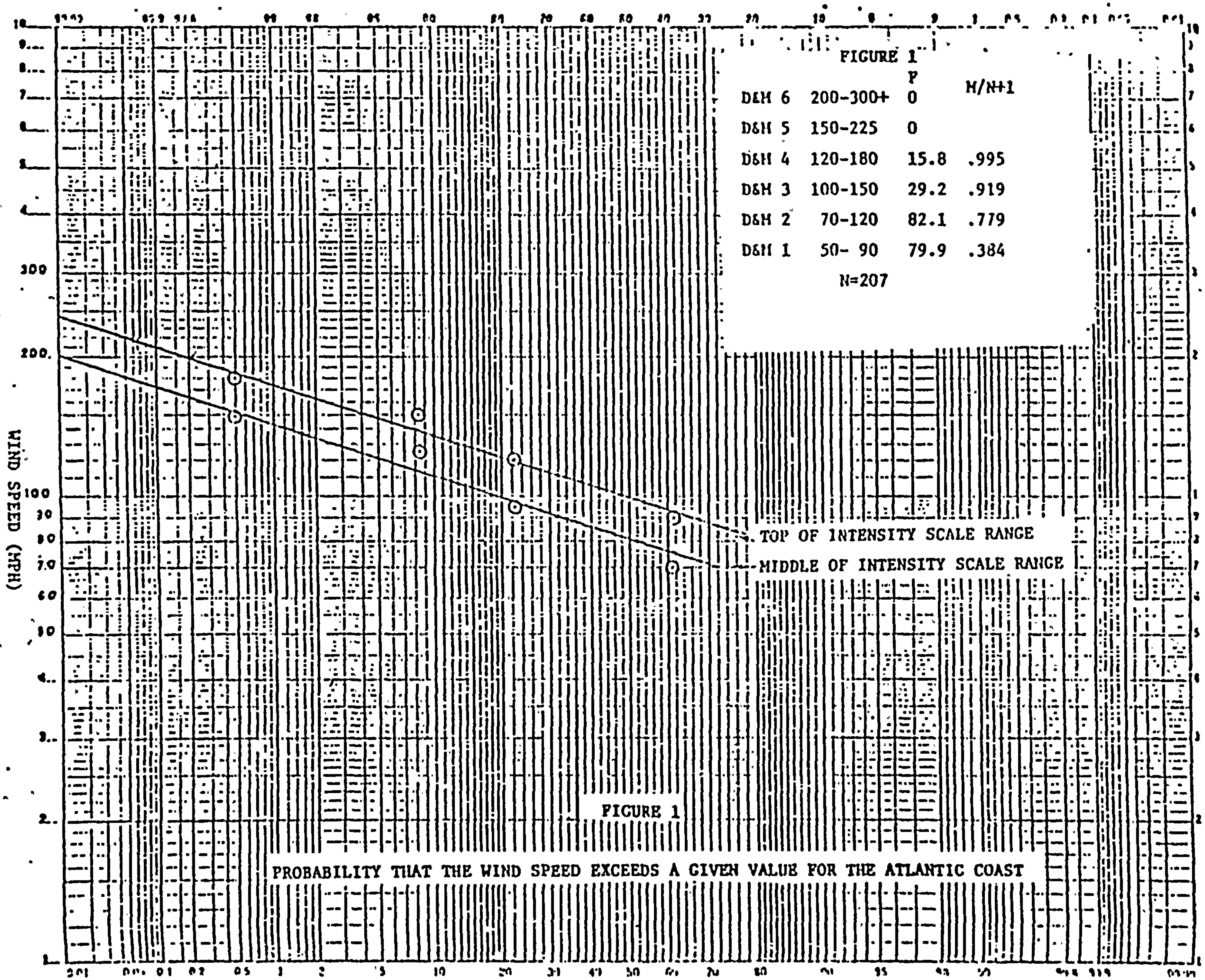


FIGURE 1

PROBABILITY THAT THE WIND SPEED EXCEEDS A GIVEN VALUE FOR THE ATLANTIC COAST

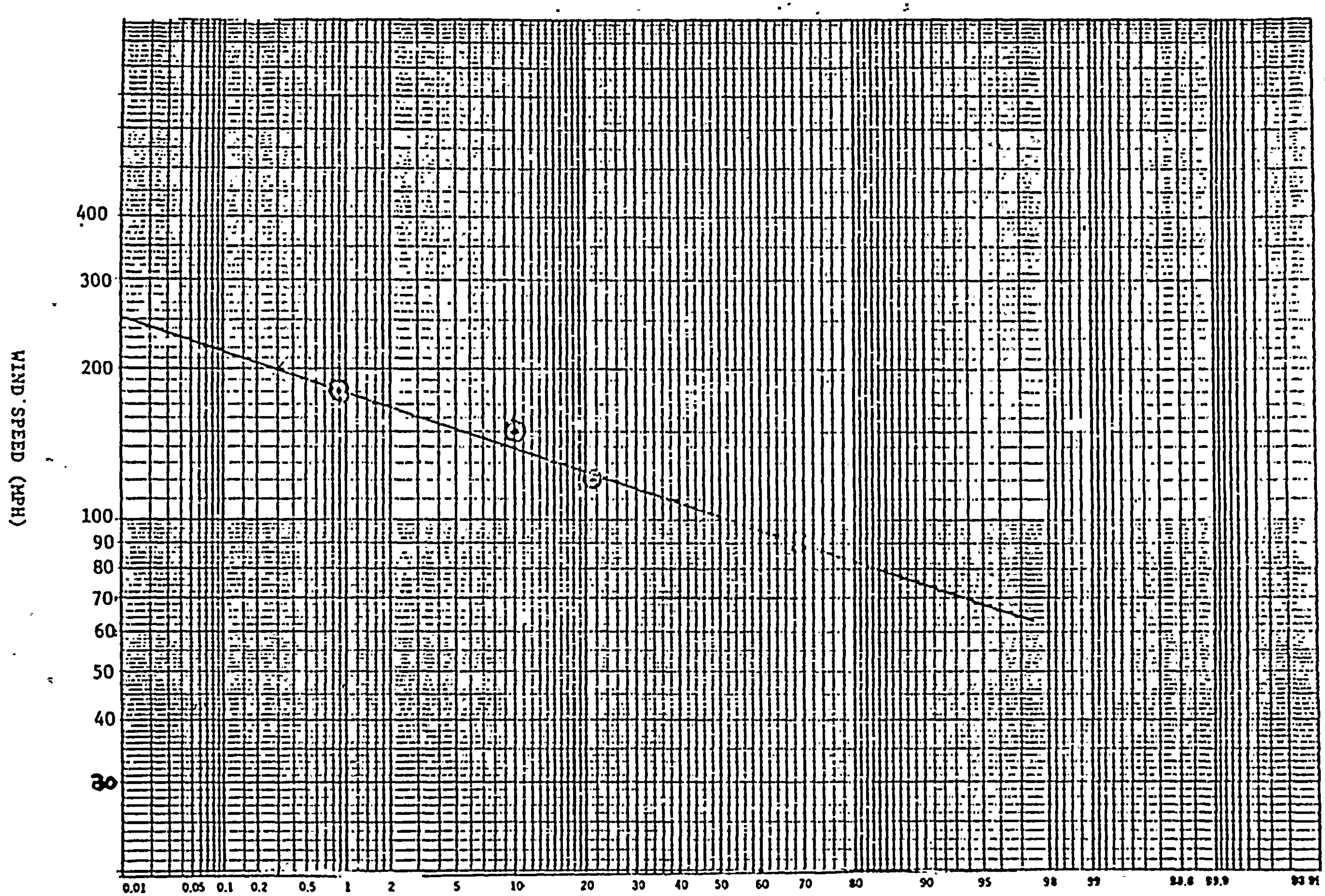


FIGURE 2

PERCENT PROBABILITY THAT THE WIND SPEED EXCEEDS A GIVEN VALUE FOR THE EAST COAST OF FLORIDA